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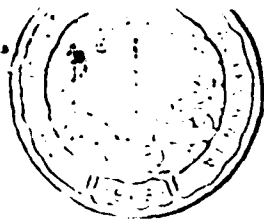
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FINAL REPORT FOR N00014-75-C-0749

Victor C. Anderson/F. N. Spiess
Principal Investigators

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<p>For six years this contract continued the core support for research at the Marine Physical Laboratory and also accommodated pass-through funds from a variety of other branches within the Navy and DARPA. The spectrum of tasks carried out under this contract is quite broad, ranging in a literal sense from the cycles per hour of the internal wave studies of R. Pinkel to the 800 kHz reverberation studies of B. Castille. The breadth of the tasks reflects the breadth of the</p>		

mission of the Marine Physical Laboratory:

"The application of knowledge about the ocean, its boundaries and the surrounding media to the solution of the Navy's problems in antisubmarine and pro-submarine warfare".

A recurrent theme in the projects is the development of innovative instrumentation for oceanic measurement of a variety of phenomena that bear upon the Navy's problems in antisubmarine and pro-submarine warfare. The extended exposure of working in the real ocean environment builds an experience base within our staff which is a resource base for the Navy. The staff of the laboratory continues to apply that experience by interacting in a direct way at many levels in the Navy; from serving on advisory committees to providing engineering support to other laboratory operations.

The tasks detailed below represent only that portion of the overall MPL research program that was supported under this contract.

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The tasks detailed below represent only that portion of the overall MRL research program that was supported under this contract.

THE COMPLEX VIBRATIONS AND IMPLIED DRAG OF A
LONG OCEANOGRAPHIC WIRE IN CROSS-FLOW

C. M. Alexander

A cylinder in cross-flow experiences periodic forcing related to the shedding of vortices in its wake. Long wires in the ocean vibrate in response to this forcing, but their length and damping is such that boundary conditions do not generally apply to solutions of the equations of motion, and their vibratory behavior at one point is of little consequence at remote points. The bulk of previous studies of vibrating wire characteristics have utilized only short wires or cylinders in the laboratory, so have not considered or even permitted this phenomenon.

During a typical deployment of the Scripps Deep-Tow survey system to depths of 2800 meters, a small 2-axis accelerometer package was attached to the tow wire at a depth of 30 meters and its output recorded in a diver-operated vehicle about 1 meter downstream. Analysis of these data produced sharply peaked spectra with the frequencies of vibration in the direction of flow twice those across the flow. Good correlations were found between mean amplitudes across the flow and the corresponding peak frequencies, and between mean amplitudes across and aligned with the flow. Preference for a specific phase relation between motions in the two planes suggests that vortex shedding occurs progressively, and the forcing function has the form of a complex wave traveling down the wire.

To investigate the implications of the preceding, a tow-tank fixture was built which permitted reproduction of amplitude, frequency and phase relations in a cylinder representing a point on the wire. A series of tests were made to measure drag force directly and obtain an empirical drag law. A constant drag coefficient of 1.8 was found in the Reynolds number range 7000-12000, compared to other investigations that have ignored vibrations in the flow direction.

COMPUTER SOFTWARE FOR NORDA'S PDP-11

William Fincke

The MPL plotting package and a variety of application software have been implemented on NORDA's PDP-11/34 minicomputer system at the NSTL site. The major applications implemented include raytracing and the mini-FACT propagation loss model, along with plotting capabilities for both. The MPL plot package was interfaced to NORDA's Houston DP-11 plotter, Printronix 300 printer/plotter, and Tektronix 4010 graphic display, allowing any software using the plot package to utilize any of the three displays. A general purpose 3-D plotting routine was also implemented under the same plot package. In addition to software specifically oriented to data reduction and plotting, word processing software developed at MPL and latest software updates to NORDA's operating system have been installed at NORDA.

William Fincke of MPL traveled to NORDA on three occasions to develop and debug the software mentioned above and to give general technical assistance in hardware selection, including the Houston DP-11 plotter, Printronix 300 printer/plotter, and DEC VT-100 video terminal. He also traveled to Nashua, New Hampshire, with NORDA personnel to assist in the acceptance testing of the NORDA Array Processing System (NAPS) supplied by Sanders Associates. On this same trip he introduced NORDA personnel to the array processor system later contracted for by NORDA from Computer Design and Applications of Newton, Massachusetts.

MISCELLANEOUS

During the course of this contract MPL has provided technological support to U.S. Navy activities whose missions involve search and survey on the deep sea floor. The work has included:

- a) modification and upgrading of shipboard cable-handling equipment for use by other groups with their own tethered, unmanned, remotely operated undersea vehicles;
- b) modification and upgrading of transducers for the side-scan sonars mounted on these vehicles;
- c) development of computer software to provide for high accuracy acoustic bottom navigation;
- d) consultation with Commander Submarine Development Group ONE and members of his staff concerning deep seafloor search equipment and techniques; and
- e) support to COMSUBDEVGRPONE with short-term loans of various equipment.

VOLUME REVERBERATION

V. C. Anderson

Volume reverberation measurements have been carried out with the multiple frequency short range echo ranging system developed under this contract. Observations in the southern California area produced quantitative measures of scattering coefficients for a variety of depths at different times in the diurnal cycle. Spatial distributions were studied with the aid of a vector current meter on the reverberation instrument package.

The results of the experimental measurements are documented in the Ph.D. thesis of Brett Castille "Characterization of acoustic reverberation in the ocean for high frequency, high resolution sonar systems", University of California, San Diego, March 24, 1978. A summary of this thesis follows:

Summary

A variable depth sonar system centered around a PDP8/E minicomputer was developed. It is unique in that the acoustic frequencies are high, 155, 227, 557, and 819 kHz, and the acoustic beams are narrow 1.6° to 6.6°. The high frequencies permitted observation of reverberation from very tiny particles, and the narrow beams combined with the depth variability allowed fine spatial resolution at short ranges. The system was used to assess some of the characteristics of the environment for high frequency, high resolution sonar systems in local waters.

Some observed values of acoustic backscattering strength are given in the form of representative vertical profiles from 0 to 500 meters in depth. Observed values ranged from over -30 db relative to 1 m^{-1} at 819 kHz down to about -90 db at 155 kHz. Very generally, backscattering strength was found to decrease both in magnitude and variability with depth. However, some interesting features were found superimposed on this, such as a scattering layer on a thermocline which was visible at 557 and 819 kHz but not at the two lower frequencies.

Individually resolved scatterers with strengths that could be expected of some of the zooplankton such as large copepods and euphausiids were observed to aggregate in layers as thin as 3 m. Thinner layers possibly exist, but were not resolved with the methods of data acquisition and statistical analysis used.

Horizontal aggregation of resolvable scatterers was seen to occur over distance scales from a few m to over a km. However horizontal aggregation on scales less than 50 m with sufficient intensity to be detected in this analysis was intermittent.

Both vertical and horizontal aggregation tended to be more intense in larger scatterers (> -72 db at 819 kHz, expected of euphausiids) than in the smaller and more numerous particles.

Reverberation from the small instantaneous scattering volumes in this study, all less than 1 m^3 , was never Gaussian. In some instances, especially in deep water, the first order probability density function of the reverberation amplitude was nearly lognormal, although significant differences in some statistical properties were always found. Individual scatterers assumed to be plankton were found to be located independently of one another when separated by more than 75 cm. They may be independently located at considerably shorter separations but this was not resolved with 1 m-sec tone bursts. No evidence suggested that the spatial arrangements of such scatterers were not Poisson processes.

Fish, however, were seen to affect each other's location at distances out to 1.5 m, a distance which may be quite variable depending on the mean fish separation.

Estimates of target strength abundance distributions of individually resolved scatterers were made by deconvolving echo level distributions with a probability density function generated by the acoustic beam pattern. Small scatterers were generally more numerous than large ones, but there are considerable local variations in the forms of these distributions in specific samples of water. There is some reason to suspect that when averaged over large volumes and time intervals, target strength abundance distributions of suspended particles may be roughly linear on full logarithmic coordinates.

FLUCTUATIONS, MULTIPATH, CAUSTICS, SOUND ABSORPTION

F. H. Fisher

During the past five years the efforts of Dr. Fisher's group have been directed towards (1) using a vertical array to study multipath arrival structure (2) developing and using a high frequency (90 kHz) narrow beam echo sounder to measure bottom topography and internal waves and (3) measuring and studying low frequency sound absorption in the ocean.

Fluctuations, Multipath and Caustics

The major thrust has been directed towards the CONTRACK series of cruises in which a large aperture sparse array (532 meter, 20 elements) is used to separate multipaths by their vertical arrival angles. By separating the various arrivals by their angles it was expected that destructive interference effects could be reduced or eliminated thereby improving array performance and leading to continuous tracking (CONTRACK) of individual multipaths. In this way fluctuations due to the medium could be studied by examining individual arrivals separately. Theoretical work by Munk and others had indicated that saturation due to micromultipath effects on individual paths would lead to incoherent acoustic energy. We found that saturation effects appear to be minimal out to long range and that signal coherence is substantial over the array aperture.

The CONTRACK I (17 January - 3 February 1975) and CONTRACK II (3 December - 14 December 1975) were initial attempts using a uniform and tapered element spacing on the array in conjunction with a beamformer. While arrival patterns were obtained, they were so complex and difficult to interpret that it was decided to go to a pseudorandom sparse array and use a minicomputer to form beams on a first principle basis. CONTRACK III (15-28 June 1976) showed that only two dominant arrivals were present as a 445 Hz source was towed at 90 m depth on a radial run. The array was centered at the axis (750 m) and runs out to 5 zones were made. However, complex FFT's on only 0.2 second samples did not allow us to do a narrow enough frequency analysis to discriminate against sea mount reflections which were suspected in parts of the record. CONTRACK IV (6 May - 21 May 1977) samples were 2-seconds long and also were obtained at 195 kHz and 400 Hz. Results out to 200 miles were obtained and clearly showed only two dominant arrivals.

These results were reported as follows:

Fisher, F. H. and Phelan, F. M., Ocean propagation experiments (OPEX I) (U), U.S. Navy Jour. of Underw. Acoust., 29(2), pp. 147-157, 1979, (MPL-C-28/78).

Fisher, F. H., and Phelan, F. M., Ocean propagation experiments (OPEX I)

- (U), Proceedings of the 32nd Navy Symposium on Underwater Acoustics, Naval Underwater Systems Center, New London, Connecticut, 14-16 Nov. 1978, V. I, pp. 307-312 (MPL-C-28.1/78).
- Fisher, F. H., Range independent fluctuations and pattern recognition of vertical angle of arrival structure (U), Proceedings of the Acoustic Fluctuation Workshop, Naval Research Laboratory, Washington D. C., 22-23 February 1978, V. 2, pp. 115-126 (MPL-C-22.1/78).
- Fisher, F. H., Range independent fluctuations and pattern recognition of vertical angle of arrival structure (U), MPL Technical Memorandum 298, 23 Feb. 1978 (MPL-S-22/78).

Following the CONTRACK IV cruise our 6.2 funding was augmented substantially by 6.3 funding from the LEAPP program, which has become the SEAS program. Efforts have been directed towards a major improvement in on-line analysis capability in preparation for CONTRACK V which occurred in October 1979. The improvements were directed towards longer samples at several frequencies so that effects of source depth, frequency and array motion could be measured.

Fluctuations

In the work with the 87.5 kHz narrow beam echo sounder it was found that even though it was designed to profile bottom topography it was capable of profiling internal wave activity very well. Results of this work were published as follows:

- Fisher, F. H., Bishop, C. B. and Squier, E. D., Results of ODEX I Experiments (U), SIO Reference 76-12, 1 August 1976 (MPL-S-26/76).
- Squier, E. D., Williams, R. B., Burke, S. P., and Fisher, F. H., High resolution, narrow beam echo sounder, SIO Reference 76-8, 1 June 1976 (MPL-U-69/75).
- Fisher, F. H. and Squier, E. D., Acoustic observation of density layers in the ocean, J. Acoust. Soc. Amer., v. 58(1), p. S102, 1975 (MPL-U-83/75).
- Fisher, F. H. and Squier, E. D., Effects of light and angle of incidence on acoustic observation of biologically enhanced layers in the ocean, J. Acoust. Soc. Amer., v. 59(1), p. S74, 1976 (MPL-U-11/76).
- Fisher, F. H. and Squier, E. D., Observation of acoustic layering and internal waves with a narrow-beam 87.5 kHz echo sounder, J. Acoust. Soc. Amer., v. 58, p. 11315-11317, 1975 (MPL-U-48/75).

It should be pointed out that this work led to the use of this echo sounder by Dr. R. Pinkel to study internal waves with doppler signal processing methods.

Sound Absorption

In the absorption experiment work CDR V. P. Simmons earned his Ph.D. by showing that the 1 kHz relaxation in low frequency absorption effect in the ocean is due to boric acid. He also made the best measurements of the $MgSO_4$ relation at higher frequencies. Results of this work were published as follows:

- Fisher, F. H. and Simmons, V. P., Discovery of boric acid as a cause of

- low frequency sound absorption in the ocean, Proceedings of the IEEE OCEANS '75 Conference on Engineering and the Ocean Environment, 22-25 Sept., 1975, San Diego, CA. IEEE OCEAN '75, 75 CHO 995-1 GEC, pp. 21-24, 1975 (MPL-U-51/75).
- Simmons, V. P., Investigations of 1 kHz sound absorption in sea water, Ph.D. Thesis, University of California, San Diego.
- Fisher, F. H. and Simmons, V. P., Sound absorption in sea water, J. Acoust. Soc. Amer., v. 62(3), pp. 558-564, 1977 (MPL-U-3/77).
- Simmons, V. P. and Fisher, F. H., Observation of the low frequency (1 kHz) relaxation in seawater using a 200-liter glass spherical resonator, Trans. 88 Meeting of the Acoust. Soc. of Amer., 4-8 Nov. 1974, St. Louis, Missouri, v. 56, p. S17 (MPL-U-74/74).
- Fisher, F. H., Chemical equilibrium constants by differential ultrasonic absorption, J. Acoust. Soc. Amer., v. 57(1), p. S56, 1975 (MPL-U-4/75).
- Simmons, V. P. and Fisher, F. H., Low-frequency sound absorption in sea water as measured in the laboratory using a spherical resonator, J. Acoust. Soc. Amer., v. 57(1), p. S56, 1975 (MPL-U-3/75).
- Simmons, V. P. and Fisher, F. H., Reaction kinetics of the apparent boric-acid-related low frequency (1 kHz) relaxation in sea water, J. Acoust. Soc. Amer., v. 57(1), p. S56, 1975 (MPL-U-5/75).
- Simmons, V. P. and Fisher, F. H., Low-frequency sound absorption in Pacific Ocean water, J. Acoust. Soc. Amer., v. 58(1), p. S85, 1975 (MPL-U-84/75).

Finally, close examination of Simmon's thesis laboratory results against selected ocean data revealed discrepancies which suggested the existence of a third chemical relaxation at 3 kHz. Subsequent laboratory work by Mellen, Simmons and Browning confirmed a third relaxation due to MgCO_3 .

- Fisher, F. H., Sound absorption in sea water by a third chemical relaxation, J. Acoust. Soc. Amer., v. 65, p. 1327-1329, 1979 (MPL-U-28/77).

HIGH FREQUENCY ACOUSTIC SCATTERING

G. T. Kaye

This research was intended to investigate high frequency acoustic reverberation in the upper 400 meters of the ocean using two devices, a narrow-beam short-pulse echosounder and a large planar array. Work with the echosounder included identification of reverberation sources at 87.5 kHz and a comparison between sound scattering layer depth fluctuations and short period internal waves. Work with the planar array at 8 kHz was to determine if backscatter from sound speed micro-structure could be separated from returns due to biological reverberation. This research resulted in the publication of five articles in refereed journals, three technical reports and two oral presentations at conferences. Some of these results are listed in the following paragraphs.

Reverberation structure has been observed from the R/P FLIP with a narrow-beam, short-pulse, 87.5 kHz echo sounder. The system resolution indicates that the backscattering can be resolved as discrete targets. Target strengths and scatterer densities suggest that the scatterers are probably fish and possibly squid and siphonophores. Although zooplankton may be observed acoustically if there are sufficient animal densities, they will not be the dominant scatterers below the mixed layer for small insonified volumes. A midnight migration was observed that corresponded with the passage of rain squalls.

The empirical relationships linking fish length and target strength for geometric region scattering were shown to apply in the case of peak dorsal values to some other marine organisms. Peak dorsal target strengths for squid, crab and penaeid prawns lie within 6 dB of the appropriate predictions for similarly-sized fish. Some zooplankton values are within similar limits provided insonifying frequencies are sufficiently high to ensure that geometric region interactions occur. The target strength data reviewed show little overall frequency dependence in the geometric region, as would be expected if the scatterers were modeled as finite cylinders.

A correlation was found between acoustic scattering intensity at 87.5 kHz and small-scale vertical temperature gradients. Prior to the rise of the Sound Scattering Layer, there was a positive correlation, which persisted for about an hour after the upward evening migration. After this time a diffuse downward migration was observed until the correlation was significantly negative. This observation indicates that the use of acoustic backscattering for remote sensing to map differing oceanic water masses has limited utility because of varying biological behaviors.

A qualitative comparison between depth fluctuations of sound scattering layers and vertical isotherm motions revealed an excellent correlation for short period internal waves. It was concluded that echo

sonder applications to the acoustic remote sensing of internal waves are expected to be quite successful. Additionally it should be expected that doppler sonar systems will be useful measurement tools for understanding dynamic ocean processes. A technique was devised to extract internal wave information directly from the short-pulse reverberation data. The technique was a tracking scheme which estimated the mean vertical motion of acoustic scatterers and then inferred the internal oscillations. Good coherence was found between isotherm depth histories and the tracking output for frequencies of 0.5-10 cycles per hour, especially in the octave of 3-6 cycles per hour.

A large-aperture, high-frequency array with sound source was used to detect returns from sound speed microstructure. Returns were infinitely clipped and numerous beams were formed by steering for curved wave fronts. The processing was a unique application of digital array phasing that allowed discrimination between returns from reflectors and discrete point scatterers. Microstructure reflections were found to be highly directional with beamformer outputs dropping more than 15 dB as the angle of incidence varied to 20 from normal. A comparison between typical target strengths for marine organisms and reflection coefficients to be expected for weak and strong microstructure reflectors showed that the detection of microstructure reflections with conventional echosounder systems will be masked by biological reverberation for almost all typical oceanic thermoclines.

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CAPER and CHURCH ANCHOR Data Analysis

G. B. Morris

Work covered under this project has been devoted to fundamental studies concerning the propagation of sound and the ambient noise in the ocean.

Most of the data acquisition, analysis and studies relate to two major exercises conducted at sea. Exercise CHURCH ANCHOR was conducted during August-September 1973 in the region of the northeastern Pacific Ocean about halfway between the California coast and Hawaii. The other exercise, the Combined Acoustic Propagation in the Eastpac Region (Exercise CAPER) was conducted during August 1974 about 400 miles west of Los Angeles, California (Ref. 1).

In both of these exercises, hydrophones were distributed in vertical line arrangements beneath the R/P FLIP. Usually the depths at which the hydrophones were positioned were selected so as to sample the water column at four key depth positions, the sound channel axis, the critical depth (conjugate depth where the sound speed is equal to that at the surface), near the surface, and near the bottom.

One study examined the depth dependence of the omnidirectional ambient noise levels for these two exercises in the northeastern Pacific Ocean. Hydrophones were positioned throughout the water column from about 200 m below the surface to 150 m above the bottom. The results showed that data from 15 Hz to 800 Hz from the two exercises could be combined on the basis of sensor position with respect to the individual sound speed profiles without regard to absolute depths. At low frequencies the ambient noise decreased with increasing depth with most of the decrease occurring in the region between the critical depth and the bottom. No wind speed dependence at the low frequencies was observed. At higher frequencies the noise levels and the depth dependence was controlled by the wind-generated noise.

The propagation loss and signal-to-noise ratios at the four widely separated hydrophone depths were determined from explosive signal data collected during Exercise CHURCH ANCHOR. The results are discussed in a classified report (Ref. 3). Analysis was made of the effects of range, frequency and sensor depths on the propagation loss and signal-to-noise ratios for a constant source depth of 18 meters. The sensor depths used in this study were 775 meters, 2492 meters, 4250 meters and 5180 meters, corresponding to depths near the sound channel axis, a depth roughly midway between the axis and the critical depth, the critical depth, and 142 meters above the bottom, respectively. The objective of the analyses was to identify source-to-receiver ranges, frequencies, and sensor positions which minimized propagation loss for the signals, and, in particular, resulted in maximum signal-to-noise ratios. Bathymetric or

changing water mass effects on the sound propagation were also noted.

These propagation loss results were also examined to determine the frequency dependent sound attenuation in this region of the Pacific Ocean. The results substantiated the findings of others that the frequency dependent attenuation in the Pacific Ocean is only half that of the Atlantic Ocean (Ref. 4).

The same analytical techniques used to study the frequency dependent attenuation for the Pacific data were also applied to archival data from the Bermuda Island region of the Atlantic. These results were given in the form of propagation loss and attenuation in a classified report (Ref. 5).

During the ambient noise measurements of Exercise CAPER, a VLCC (Very Large Crude Carrier) or supertanker, the Chevron London, passed through the region greatly influencing the background noise levels (Ref. 6). The tonal associated with the propellor blade rate and its frequency harmonics were clearly observed on single, omni-directional hydrophones for ranges out to 240 nautical miles. Broadband source levels in the 50 Hz one-third octave band for this vessel were estimated to be between 185 and 195 dB/1μPa. Moreover, the measurements showed a strong directivity pattern for the radiated noise of this vessel. Near abeam the strongest blade line harmonics were in the 50 Hz to 70 Hz band. For the near stern radiation, the strongest line were in the 40 Hz to 50 Hz band. Perhaps the most significant conclusion of the analysis of this supertanker noise is the slope enhancement of the acoustic output as the vessel crossed the steeply dipped continental slope. This slope enhancement was measured at four widely different depths from near the surface to near the bottom. This slope enhancement, or the increase in far-field measured source levels when the vessel neared the continental slope, amounted to 5 to 10 dB with the shallower hydrophones showing the largest increases.

In 1977 the emphasis shifted from omni-directional, single sensor analysis to configuring the hydrophones as a 20-element vertical array (see Vertical Directionality of Ambient Ocean Noise, page 17).

During this contract period several reports were issued which described other effects related to the main objectives of the research. One report described the analog tape recordings made during particular phases of the CHURCH ANCHOR Exercise (Ref. 7). Another report described the advantages and potential for using the R/P FLIP as a general purpose platform for measuring the radiated noise levels of the surface ships (Ref. 8).

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INTERNAL WAVES

Robert Finkel

Under the terms of this contract, a program was funded to develop Doppler sonar techniques for the study of water motion in the upper part of the sea. Feasibility studies were initiated in 1975, followed by prototype tests in both ocean and fresh water lakes in 1976-7. Based on this experience a set of four Doppler backscattering sonars were constructed, under cooperative support of NORDA (Codes 500 and 541), ONR Code 480, and NSF. These were designed and tested in 1978-9 and used in a highly successful FLIP cruise in May 1980, to study the directional properties of upper ocean internal waves. In the following paragraphs the motivation for the work will be discussed. Then the results of the early tests will be outlined, followed by a description of the Doppler backscattering sonars constructed. A description of the May 1980 FLIP cruise will conclude this section of the report.

Internal waves are ubiquitous in the upper ocean and constitute a dominant source of disturbance of the ocean interior on the smaller scales of interest to the Navy. While the levels of internal wave activity are now fairly well known, the directional nature of the propagation of these motions is poorly understood. Since internal waves constitute the dominant "background" against which highly directional man-made disturbances must be detected, it is vitally important that the directionality of the wavefield itself be determined. This is a difficult task. To sense the direction of wave-propagation, underwater "antennas" have to be constructed, having dimensions comparable to the wavelength of the waves. These range in horizontal size from a few meters to many kilometers. Constructing an antenna which physically spans this range of scales is not feasible. The most successful attempt was in the 1972 IWEX experiment in which a complex tri-moor was deployed in the deep sea, on which many current meters and temperature sensors were suspended. While mooring technology has been improved in the last decade, attempts to improve upon the IWEX results in the upper ocean have not been successful. The variable currents in the upper few hundred meters are strong enough to cause significant mooring motion problems. At MPL, Doppler sonar has been developed as an alternative approach. Here, high frequency sound is transmitted in a narrow beam. The sound scatters from the plankton (and nekton) in the beam. From the Doppler shift of the backscattered echo, the component of scatterer velocity can be determined at many ranges. Several such sonars, mounted on the research platform FLIP and pointed in different directions can be used to achieve the "directional antenna" necessary for internal wave propagation studies.

Preliminary tests of this concept were started in 1975-6, by which time Doppler radars had been well established. It was important to both develop the acoustic technology and to investigate the extent to which radar principles could be applied to scattering sonar. Tests were

conducted in Lake San Vicente, east of San Diego, on several prototype systems ranging from a simple pulse-echo incoherent sonar to an infinite time-bandwidth coherent sonar. The general impression resulting from these tests is that, while the radar methods can be carried over to sonar, sound travels too slowly in water relative to the motion of the scatterers to capitalize on many of the techniques developed in radar. The same basic principles have to be applied from slightly different points of view. Also many of the intuitions developed in the efforts to detect a "discrete" target in a random noise field must be modified when dealing with a random "cloud" of scatterers. These findings were summarized in a NATO text article "On the Use of Doppler Sonar for Upper Ocean Velocity Estimates".

Following this basic research, an existing 87.5 kHz sonar was borrowed from Dr. Fred Fisher of MPL for actual sea tests. In January 1977 approximately two weeks of high quality Doppler data was collected. It was then time to proceed with construction of a FLIP based multi-sonar array. By October 1980, a four sonar system was constructed under the combined sponsorship mentioned above. Two large sonars and two smaller ones were created. Each of the larger sonars consists of 1680 discrete transducers which are mounted on a flat plate to produce a hexagonal array of 1.5 m mean diameter (Fig. 1). Each array is driven at 32 kw peak power at frequencies between 70 and 85 kHz. At these frequencies, the beamwidth is theoretically less than 1°. Useful ranges to 1.6 km have been achieved, depending on the biological scatter levels (Fig. 2). Range resolution is adjustable. At typical resolution lengths of ≈ 25 m, a velocity precision of ≈ 1 cm/sec rms can be achieved after 30 seconds of ping to ping averaging. The smaller sonars, constructed of spare parts from the larger ones, measure approximately 1.5 x 0.8 m and are driven at 8 kw peak power.

In order to best study the directional properties of internal waves, the sonars were positioned on FLIP as follows: the two large sonars were mounted at a depth of 85 m (with FLIP vertical) with beams directed horizontal, and at right angles to each other. These, when used in a "Mills cross" fashion, will provide the desired information on the directional properties of the waves. The smaller sonars are mounted higher on the hull, 30 m depth, with beams directed downward at a 45° angle. These monitor the shear field in which the internal waves have to propagate.

The complete system, in addition to an automatically profiling CTD and numerous environmental sensors, was tested in short cruises in Nov. 1979 and Jan. 1980. During May 1980 eighteen days of continuous measurements were made in the deep sea 400 km southwest of San Diego. Over four million independent velocity measurements were made by the sonars, in addition to some 12 thousand CTD profiles. The data set is comparable in size to that from the Polymode Experiment, which lasted for a year and involved investigators from many nations.

This contract closes with the analysis of the May '80 data set just beginning. In excess of 200 magnetic tapes recorded on the sea trip have been duplicated. Detailed processing is now starting. The technical feasibility of Doppler sonar for internal wave measurements has been

clearly established.

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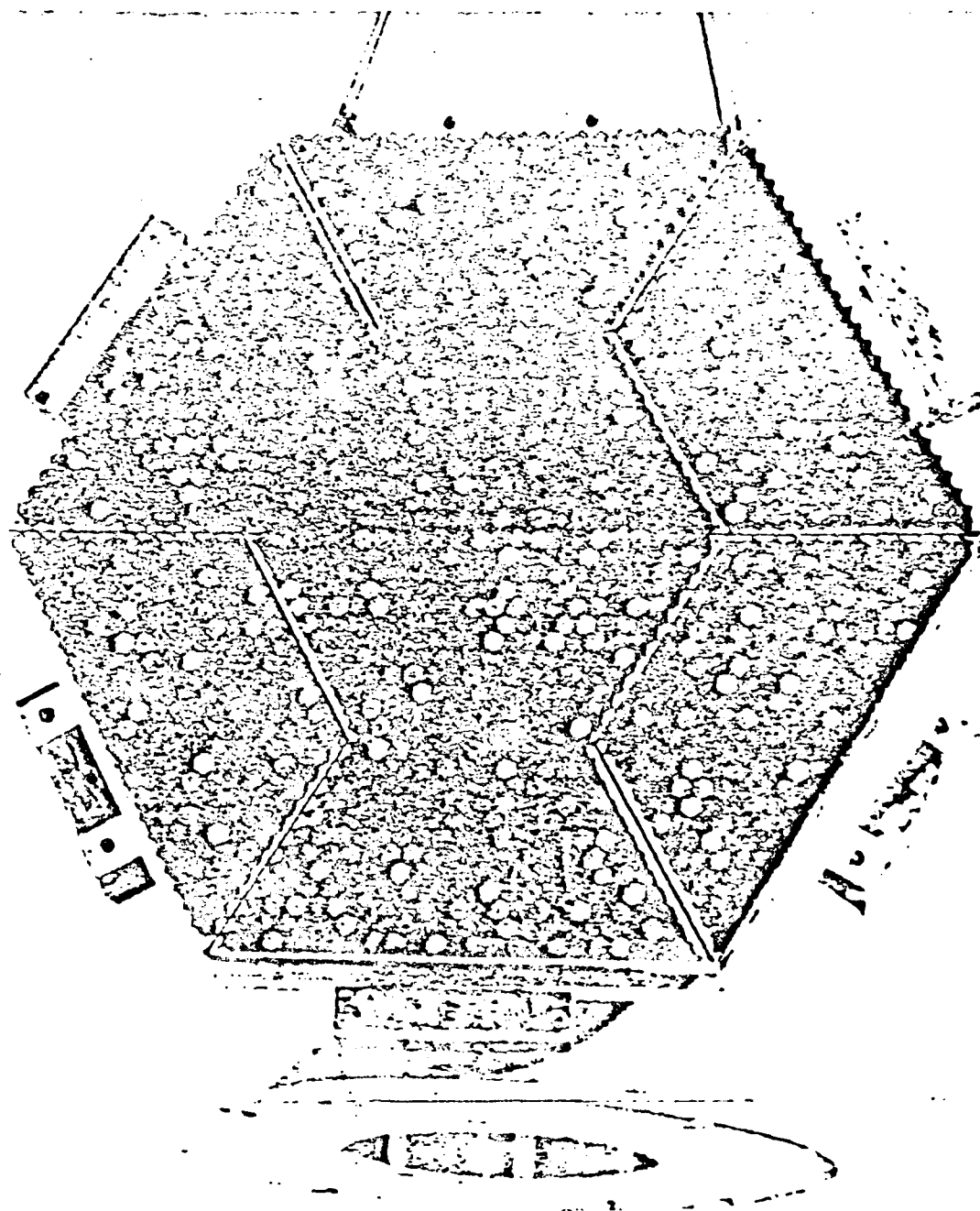


Figure 1

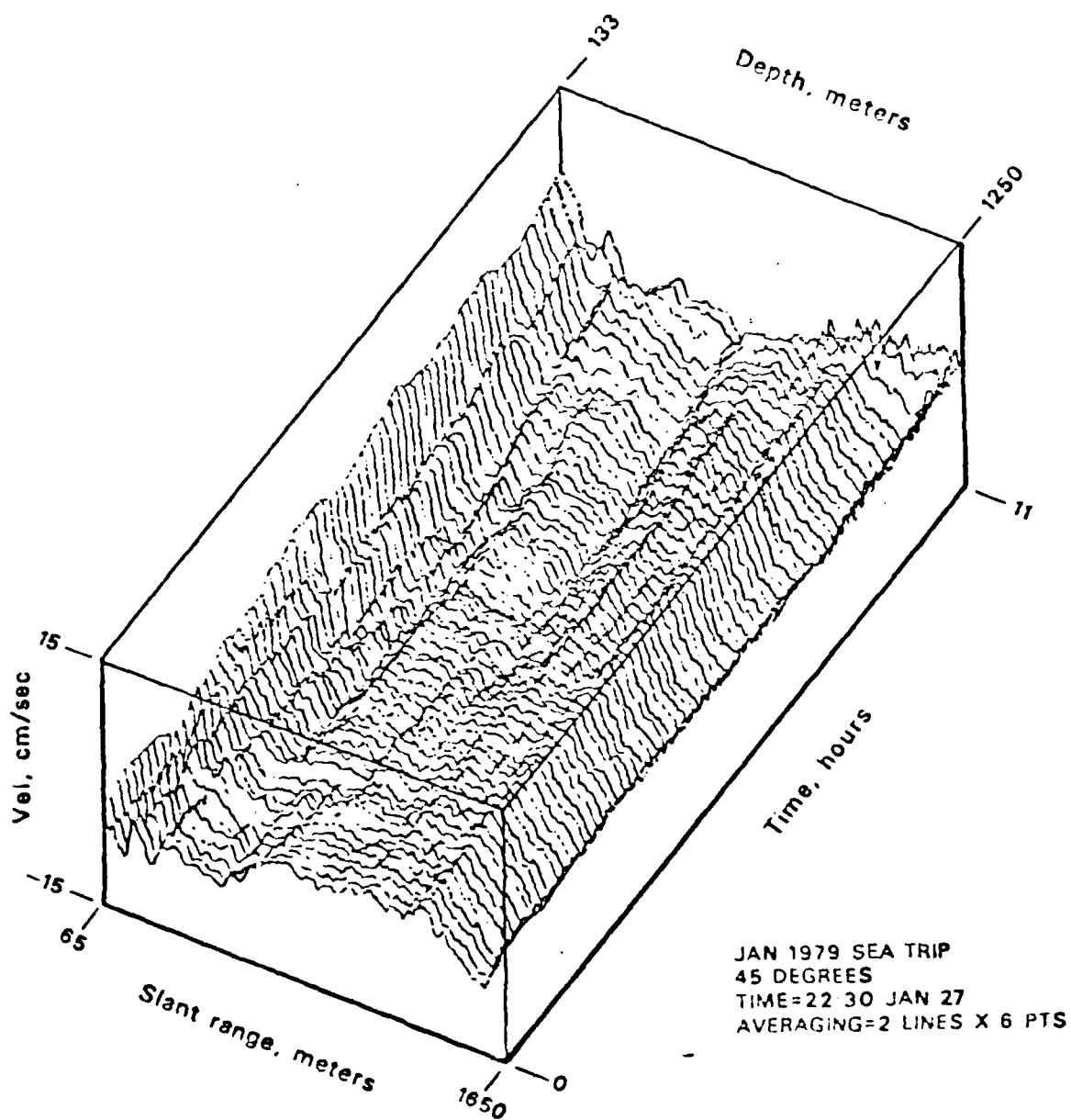


Figure 2

VERTICAL DIRECTIONALITY OF AMBIENT OCEAN NOISE

R. C. Tyce

During the last five years, the research group formerly under Dr. Gerald Morris and more recently under Dr. Robert Tyce has been concentrating on studies of low-frequency ambient ocean noise.

It has been clear for a number of years that distant shipping is the major contributor to ambient ocean noise in the 20-200 Hz frequency range (Wenz, 1962). In the deep ocean, where long-range propagation is possible, the ships which can contribute to the ambient noise field are large in number though certainly not uniform in distribution.

Much of the work at the Marine Physical Laboratory, essentially since its beginning, has been aimed at understanding ambient noise in the ocean. Building on previous work at the lab, part of our efforts during the past few years have been aimed at understanding and quantifying the directional and depth dependence of low-frequency ambient ocean noise.

The earlier work on depth and directional dependencies of ambient noise has been published in several papers by Dr. Morris and Dr. Anderson, particularly Anderson, 1979a, 1979b, and Morris 1975, 1978.

Earlier work at MPL established interesting depth dependences of low frequency noise as well as indications of significant vertical directionality. During May 1978 and April 1979 two separate FLIP cruises were conducted to obtain detailed measurements of vertical directionality and its dependence on depth in deep water.

The May 1978 experiment concentrated on the frequency range from 10 to 50 Hz. With FLIP moored at a location 350 miles west of San Diego in water 4300 m deep, a 20 element array 532 m long was deployed vertically to five different depths over a period of several days. More than 90 digital tapes were recorded with individual hydrophone data for beamforming later ashore.

The data from this expedition has proven extremely good, with only one hydrophone malfunctioning during the experiment. Much of our initial efforts at processing the data were aimed at optimizing side lobe rejection in the beamforming process, to obtain a high degree of vertical resolution.

As a result, better than 30 dB side lobe rejection was achieved on the real data for 16 or more channels. The data themselves show primary concentration of ambient noise in this frequency range between ± 13 deg off horizontal for the array centered at the sound channel axis. The noise level drops dramatically outside this ± 13 deg sector to levels more than 25 dB lower.

This angular section decreases with increasing depth so that when the array is near bottom, the measured beam noise is concentrated in an angular sector of ± 4 deg as measured from the horizontal.

The initial results from this expedition were presented in a paper by Morris and Tyce at the December 1978 Acoustical Society meeting.

For the April 1979 work the vertical array was reconfigured to concentrate on the frequency range from 50-300 Hz. This frequency range represents the transition region from ship-dominated to sea-state-dominated ambient noise. Here the vertical array was deployed to the same five depths as in the May 1978 experiment, ranging from near the surface to near the bottom, at essentially the same location as before.

During four days, more than 300 tapes of data were collected during this expedition, with only a single significant hydrophone failure. The data here show a gradual reduction in directionality from 50 Hz to about 175 Hz, where directionality is reduced to only a few dB difference between horizontal and overhead directions, with wind speeds of 20-40 knots.

Between the 1978 and 1979 expeditions we have an excellent ambient noise data set from 10 to 300 Hz. Analysis of this data set is on-going and includes various studies of beam and element noise statistics as well as studies of envelope spectra.

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LOW FREQUENCY RESIDUAL NOISE FIELD PROGRAM

R. C. Type

Building on our previous work on the structure of background noise in the ocean, an effort to study the residual noise field was begun under this contract.

Almost as soon as it was realized that the low frequency noise heard by omni-directional hydrophones in the deep ocean was primarily ship generated, it was realized that at some level of discrimination the noise field would become non-isotropic, separating into single or multiple ship components and a residual background noise field. This residue is the background which will limit truly high performance passive systems, and at least part of it will become the principal background in the event of drastic control of shipping which could occur in times of emergency.

Making significant use of current capabilities, we have been endeavoring to develop a capability for measuring the residual noise field. Our current design involves a long horizontal array attached at one end to a heavy pressure case suspended from FLIP in a 3-point moor. The other end of the array is attached to an additional line, anchored and buoyed in the vicinity, by means of a line crawler. By proper choice of weight, buoyancy and anchor position, the array can be held with proper tension, and positioned at any desired depth by means of the remotely operated line crawler.

Our efforts during the past two years have involved the design and testing of the various aspects and components of this system. These include array navigation, array telemetry, array deployment and handling, and line crawling capability. Our efforts included investigations into the developing Kevlar array technology, particularly involving adaption of the techniques developed by the NORDA VEKA group under R. Swenson.

During May 1979 an expedition was undertaken aboard FLIP, with the participation of the NORDA VEKA group. This cruise was intended to test navigation, deployment, and line crawler techniques, as well as collect environmental data. With FLIP in a three-point moor north of San Clemente Island in 1000 m deep water, MPL and VEKA arrays were deployed in both horizontal and vertical modes. Array localization experiments were conducted using various sound sources. Background and shipping noise measurements were also made.

More specifically, a nine-channel VEKA II array was deployed horizontally from FLIP, and later adjusted to a vertical mode. A ten-channel MPL array was deployed vertically from FLIP, then recovered and deployed twice horizontally to 400 m depth by means of the line crawler. Array localization experiments were conducted for all four array configurations using 1500 Hz transducers and transponders, practice SUS charges, seal control charges, and various projectiles. Recordings of ambient noise and ship traffic were made for evaluation of the VEKA array and studies of the noise properties of the Catalina Basin.

The cruise was extremely successful, with all deployments yielding useful data. The participation of the MITA group gave us invaluable insight into potential applications of the Kevlar array technology developed by that group, as well as possible cooperative efforts. A discussion of the VEKA/FLIP array deployment has been published in the Marine Technology Society Journal (Swenson et al., 1980).

On-going work for this project includes design and development of a new microprocessor controlled telemetry unit for local beamforming in order to achieve optimal resolution with a minimum of array channels. Present plans include a 40 channel array approximately 100 wavelengths long at 100 Hz with transponder localization. Initial deployment of this array for environmental measurement is planned for FY82. It is anticipated that NORDA VEKA technology will be involved in array construction and deployment, as well as possible cruise participation.

Considering the system resolution implied above and the base from which we operate, the initial seagoing work will be carried out off San Diego in the deep ocean (after an initial shallow water test) with azimuthal sectors pointed north-south. On-board data processing equipment will provide for narrow band spectral and statistical analyses as well as data recording. Subsequent observations will be conducted both with and without use of major topographic features to block input from one or the other of the reciprocal segments toward which the broadside direction of the linear array will be oriented.

These ambient noise studies will establish the limits on low frequency passive sonar performance and will be particularly exciting since they will open an aspect of ocean acoustics which is virtually unexplored. It is quite possible that they will provide substantial new viewpoints on the long-range detection problem as well as the fundamental nature of noise in the sea.

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Acoustic Transmission

W. Munk, G. Williams, P. Worcester, and B. Zetler

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DEEP TOW IMPROVEMENTS

F. N. Spiess

The Marine Physical Laboratory's deep-tow engineering group initially received funds to undertake four tasks which would substantially improve our ability to conduct fine-scale sea floor topographic surveys and speed the necessary related data reduction process.

The tasks were as follows:

1. Transponder versatility.
2. Improved topographic resolution.
3. Data processing.
4. Positive sub-bottom profiling.

Task 1 was to modify our fish and ship transponder interrogation capabilities so that we could work with AMF or other transponders than our own (see DCSD 1359, item 1). This was completed.

This contract work program was modified by a letter (PME 124) which added the task on the roughness processor and allowed us to defer completion of all the tasks, within the framework of the successor to this contract, to which some PME 124 funds were added for the purpose.

The improved topographic capability and transponder versatility items were completed and tested at sea in March-April 1980 during NSF-funded MANOP surveys. The data processing element is also complete and work on the sub-bottom profiler and roughness processor is continuing under the successor contract.

SOUND PROPAGATION IN THICK SEDIMENTS

G. G. Shor, Jr.

During the period of this contract, the primary work of the group under Shor and Raitt was the determination of fine-scale variations of sound velocity with depth in thick sedimentary sections in the seafloor, and the determination of attenuation of sound waves as a function of depth in the same areas. In the process of doing this we developed some new hardware and techniques for study of the seafloor. One item of hardware was a long (6 km) towed near-surface array and a digitization system to go with it; another item was a set of inexpensive moored telemetering/recording buoys for seismic work; a third was a set of free-fall recording ocean bottom hydrophones, which record signals over a wide dynamic range and return to the surface at a pre-set time. The second and third sets of equipment have been highly successful, and with them we have made observations of sound-wave arrivals from deep explosive shots to deep and shallow receivers. These observations have provided data on sound velocity variations as a function of depth in the sea floor over ranges of depth that are difficult to study using shallow sources or receivers. The best set of data, from the central portion of the Bengal Fan has provided a precise determination of velocity with depth, and a determination of attenuation as a function of depth, showing that the attenuation coefficient, high near the surface of the sediments, decreases rapidly at depths near 600 meters and drops to a value in the deeper part of the sediment section that is little, if any, greater than in hard rock sections. The depth at which the attenuation begins to drop is approximately the same as the depth at which the gradient of velocity with depth begins to drop from its high initial values to a lower rate of increase, leading one to believe that the effect is primarily one of consolidation -- the depth being that at which grains in the sediments are in firm contact due to the weight of the overlying material. Work on this project is continuing under a new contract, with the goal of determining the attenuation and its variation with depth in a wide variety of oceanic environments.

MICROBATHYMETRY SURVEY

F. N. Spiess

The deep-tow instrument system was used to provide technical services in support of a microbathymetry survey required for the Naval Electronics System Command. The survey was carried out during March 1978 utilizing USNS SILAS BENT operating out of Yokosuka, Japan. Deep-tow topographic data were reduced to contour chart form and delivered directly, along with the original side-looking sonar and photographic materials to NAVELEXSYSCOM (PME 124) for interpretation.

SEA FLOOR SHAPE

F. N. Spiess

In order to provide more detailed information about the seafloor shape (slope and curvature across track), an interferometer side-looking sonar was designed, constructed and tested at sea as an element of the deep-tow instrument system. Subsequent equipment modification and data acquisition has been supported by CNR-Code 480.

SEA FLOOR REFLECTIVITY

R. C. Tyce

For more than a decade the Deep Tow group at MPL has been improving its ability to make near-bottom geophysical and acoustic surveys of the deep sea floor. The proximity of the deep tow vehicle to the sea floor permits lateral resolution of acoustic properties of the sea floor which cannot be obtained from surface vessels.

During the last five years a system for quantitative seismic profiling was developed and refined into a valuable research tool. This system has resulted in several Ph.D. theses and a number of significant papers.

Beginning as a simple 4 kHz echo sounder, a computer processing and display system was developed. After acquiring data on tape for several years, a real time system was developed to produce quantitative data displays alongside the old analog displays. The result is a valuable geologic and acoustic tool for deep ocean survey work. The development of the system is documented in a paper by Tyce (1977).

The application of this system has revealed significant variability in reflectivity of the sea floor and for buried reflectors on a very small scale. Over lateral distances of a few meters, 7 dB changes in overall reflected energy as well as 10 dB changes from individual reflectors have been observed. Extreme variability from volcanic basement is seen to be common, requiring a scattering model at this frequency.

Anomalously high amplitudes from buried reflectors together with abrupt reflectivity changes from buried reflectors caused us to add a 6 kHz capability to the 4 kHz system. This allowed us to observe whether or not multi-layer interference was a significant effect at these frequencies, as we suspected it was. The considerable differences between 4 and 6 kHz profiles in many areas suggest that multi-layer interference is a significant effect for pulsed CW profilers such as this.

The very small scale lateral variability observed in many areas also suggests that very localized phenomena play a major role in sedimentary processes.

Despite the variability and interference which we commonly observed however, this quantitative profiler has proved invaluable to studies of geochronology and attenuation of sound in sediments. The detailed physical and chemical property studies of core samples taken by Dr. L. Mayer (1979) along a quantitative profiler track provided one of the few successful correlations of physical and acoustic properties which have been achieved in recent years.

In addition, the real time quantitative profiler plots have proved invaluable for estimates of acoustic attenuation from sediment wedges and dipping reflectors, which appear surprisingly common in the deep sea. A wide range of values for various sediment types have been observed ranging from 0.12 to more than 0.65 dB/m at 4 kHz. Surprisingly low values for calcareous sediments were discovered, suggesting an unexpected trend to markedly lower attenuation for biogenous sediments. More work in this area is clearly indicated.

Publications on the subject of attenuation in particular as well as on reflection loss variability and anomalous amplitudes are presently in press.

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SIGNAL PROCESSING

V. C. Anderson

Signal processing investigations under the contract have been varied in nature and have, to a large extent, served as input to other projects rather than being an end in themselves.

One of the more extended investigations is one directed towards the application of F. V. Hunt's "Sic Transit Sonitus" algorithm for detection of the transit of a target past a receiving hydrophone. After F. V. Hunt's death, Dr. Philip Rudnick (who retired from MPL in 1969) offered to assist in the project on a volunteer basis. Analysis of data collected from a bottom hydrophone installed off the end of Pt. Loma has been completed and Dr. Rudnick is preparing a final report which unfortunately is a negative one with respect to the applicability of the algorithm in the environmental noise field. The reason behind the negative conclusions lies in the non-stationary nature of the ambient noise in the ocean.

The rekindled interest in noise stationarity that developed out of the "sic transit sonitus" experiment gave rise to a paper on the envelope structure of noise and signals in the 20 to 100 Hz frequency band as observed on the LRAPP 20 element vertical array from FLIP, and also one treating the envelope structure of noise in the 800-3200 Hz band as observed with the ADA array.

During this contract period two visiting scientists, Prof. Ted Birdsall of Michigan and Prof. Franz Tuteur of Yale, spent periods in residence at MPL, interacting with the staff and the seagoing MPL research programs. Dr. Birdsall applied signal processing techniques to the analysis of shot data, removing the artifacts associated with the bubble pulses so that the frequency dependence of acoustic transmission loss over very long range paths could be more precisely determined. Dr. Tuteur and J. Presley, a graduate student, developed a method of estimating input spectra from the output of an infinitely clipped (DIMUS) beamformer.

Another signal processing topic was the comparison of two techniques for height finding in an echo ranging sonar. Specifically the study relates to the comparison of a phase difference method where a split transducer is used and a time difference technique where two separated transducers are used, with height information derived from triangulation using travel time differencing in the echo arrival at the two receiving transducers. Part of the study relates to the manner in which the 3-D information is displayed to the operator, in particular by the use of a stereo imaging display. This study is part of a Ph.D. thesis in preparation.

ENVELOPE SPECTRA FOR SIGNALS AND NOISE IN VERTICALLY DIRECTIONAL BEAMS

Victor C. Anderson

A vertical line array operated from the research platform FLIP was used to obtain directional samples of deep-water signal transmission and background noise over a period of three days. The data are analyzed to obtain estimates of envelope spectra for both signal and noise. Significant differences between the envelope spectra of signals and noise are observed. Comparisons are also made between the acoustic signal on single hydrophones and those from the electrically steered beams. The single hydrophone exhibited a much higher temporal variability of amplitude than did the beam data. Limited evidence indicates that spatial variations across the array were not solely due to interference between major multipath arrivals, but may be, instead, scintillation produced by an inhomogeneous medium.

(Abstract from J. Acoust. Soc. Am., v. 65(6), p. 1480, 1979.)

DYNAMIC BEAMFORMING

W. S. Hodgkiss and V. C. Anderson

Background

The concept of coherently summing together the signals arriving at the individual elements of a drifting sonobuoy array stimulated work by the Marine Physical Laboratory to fabricate a dynamically programmable beamformer. As conceived, the drifting collection of sonobuoys would be a sparse array, i.e., one where the average separation between elements would be much larger than one-half of a wavelength at the frequencies of interest. The net result of having only a few elements thinly spread across a wide aperture is that the number of resolvable listening directions or "beams" that could be formed by first time delaying, then summing the individual sonobuoy signals, would exceed by a factor of 100 to 1000 the number of elements themselves. Also, the time varying geometry of the freely drifting sonobuoys meant that the set of time delays required for each desired listening direction would need to be dynamically adjustable. This requirement for a very large number of beams being generated from a time varying array geometry was the essence of the dynamic beamformer problem.

The hardware which has been fabricated permits the incorporation of slow changes in element positions and beam steering direction while the beamformer carries out the real-time formation of 1300 beams from 32 input sensors. The sensors are distributed in a random, but known manner over an aperture diameter of up to 3000 meters. Their positions are determined by a separate array element location system (designed and fabricated by the Naval Ocean Systems Center) which makes use of several active buoys within the predominantly passive sonobuoy field.

Progress to Date

Design and construction of the Dynamic Beamformer was initiated in FY77 under MPL proposal UCSD 0723 and completed in FY78 under MPL proposal UCSD 0959. The design of the Dynamic Beamformer was carried out in cooperation with the Naval Ocean Systems Center, particularly with regard to data format and system interface.

In FY79 under MPL proposal UCSD 1318, the Dynamic Beamformer underwent system integration tests with the remaining Naval Ocean Systems Center equipment. Dynamic Beamformer software modifications were made to permit masking of the input data channels so that the first 32 "beams" of a beam scan actually correspond to the individual channel signals. In July 1978, MPL participated in the first STRAP (Sonobuoy Thinned Random Array Program) sea test.

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